Taguchi optimization for the Processing of Epon SU-8 Resist

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Abstract

Using the Taguchi Method's technique of orthogonal arrays, an optimization experiment was performed to characterize the processing of Epon SU-8 negative photoresist. This photoresist has proven to be very sensitive to process variations and difficult to use in the creation of useful films. The Taguchi method reveals output sensitivity to variations in process para meters. The experiment was repeated for four film thicknesses: 25μm, 100μm, 250μm, and 500μm. The optimization output concentrated on straight sidewall profile, fine line and space resolution, and adherence to subst rate. Plots show optimal processing parameters for these four film thicknesses.

Introduction

High aspect ratio micromachined structures have many useful applications. Currently there are few techniques to achieve such strictures. These include LIGA, plating with thick photoresists, and Deep RIE molds. The LIGA technology crest es the highest aspect rat io's available, but needs a synchrotron radiation source for its application with a cost prohibitive to many potent ial users. Plating thick photoresist, perhaps with multiple coat ings, is another method to achieve high aspect ratio structures. This is cheap and uses standard optical lithographic techniques. However the thickness achievable is limited by high optical absorption of novolac photoresists. Both these methods provide a dielectric necessary for plating metals, something D.R.I.E. does not.

Epon SU-8, a relat ively new product, was first researched as a possible useful thick film by IBM. SU-8 has a low opt ical absorpt ion, thus allowing the patterning of very thick films (> 1mm). It also has a high functionality which results in a high degree of cross-linking, producing straight sidewall profiles and high aspect ratios. SU-8 is non-conductive, and so can be used as a dielectric in electroplat ing. Potentially, SU-8 has many of the advantages of the other thick film techniques, and few of their disadvantages.

However, iu practice, SU-8 has pi oven to be very sensitive to variations in processing variables and hence difficult to use in the fabrication of useful structures. The literature has a wide variation in values for processing parameters. For these reasons it was necessary to perform an optimization experiment to determine the correct values of the processing parameters for SU-8.

In this paper we will describe in detail the experiment for the 100μm thick film. The results obtained for the 25μm, 250μm, and the 500μm films were obtained using the same methods and the overall results will be shown in that section.

The Taguchi Method

The application of the Taguchi Methods of Process Design was indicated as the proper means of optimizat ion for SU-8 resist. The methodology is bad on the orthogonal array technique, signal-to-noise ratio, and analysis of variance (A NOVA). Five parameters at four levels each were selected iu the experiment. A full factorial would have required a total of 1024 experiments (45). The orthogonal array t echnique required only 16 experiments. The measured outputs or quali ty characteristics to be optimized included sidewall profile, film adherence to substrate, and line and space resolution. From the 16 experimental results, and using the ANOVA software, the "sensitivity analysis" of the parameter level contribution to desired quality characteristic optimization was predicted. Confirmation experimental trials were performed to validate theoretical prediction.

In our experiment we focused on 5 variables: softbake time, exposure time, post exposure bake (PEB), develop time, and the type of substrate that the SU-8 was spun onto. Our test space was large because of the high degree of uncertainty of each variable.

Experimental Results

We found that, in general there were three problems associated with incorrect process parameters. We call these "top etching" (Fig 1), " bottom etching" (Fig 2) , and poor resolution (Fig 3). In the first case, a thin crust forms on the structure and during the development the pattern under the crust will develop away at a rate less than the unexposed area, but great enough to significantly affect the sidewall profile. In the bottom etch case no crust is formed, but the film close to the substrate will develop away and if left long enough in the developer the structures will float off the substrate. This resembles poor adhesion, but is actually clue to undercutting of the pattern. Poor resolution describes closely situated lines wit h undeveloped resist in the spaces between them .

In view of these problems, we optimized for three results: straight sidewalls, adhesion, and resolution (no top etch, no bottom etch, and fine resolution.)

Figure 8 shows the result of the optimization. The labels $A \rightarrow E$ relate to the variable being analyzed (Table 1). These results indicate that there are conflicting parameter values depending on which result we opt imize for. The PEB is particularly troubling because the various optimizations seem to indicate that it is difficult to achieve both straight sidewalls and adhesion. However, the large spread in the chosen data points could be the source of this apparent conclusion. Using the optimization results as a base, further refining was done in the area of PEB and exposure time to achieve the best results Of all the desired output s.

We performed a similar experiment for three other film thicknesses: 25μm, 250μm, and 500μm. [1]

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[1] Experiments and analysis of 25μm, 250μm, and 500μm are currently in the process of being completed. The data points in figure 9 for these film thicknesses project cd.

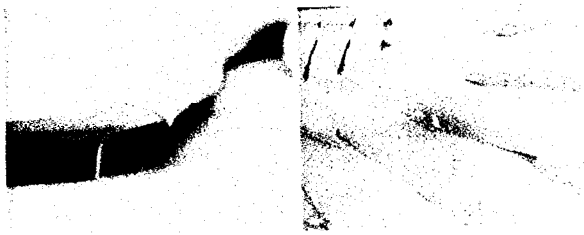


Figure 1 A crust forms on the top of the film

Figure 2 Film near the substrate develops away resembling bad adhesion.

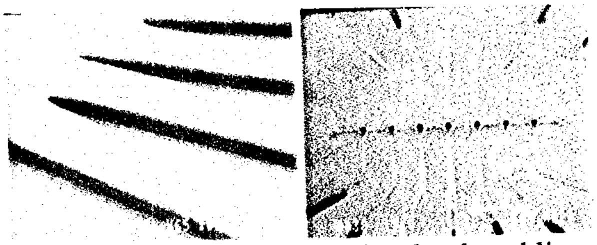
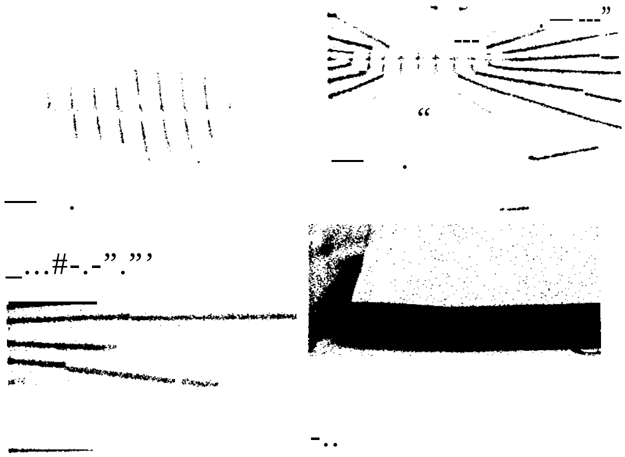


Figure 3 Spaces between closely placed lines may not develop due to crosslinking.



Figures 4-7 Confirmation of results of optimization process.

Table 1

Label	Parameter	Points 1	2	3	4
A	Soft Bake	10m	15m	30m	1hr
B	Exposure	30s	2m	15m	30m
C	PEB	30s	2m	15m	45m
D	Develop	5m	15m	30m	1hr
E	Substrate	Au	Si	SiO_2	SiN

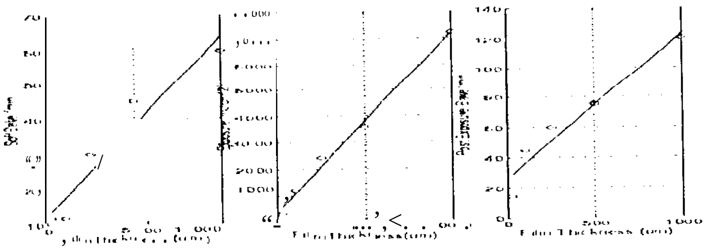
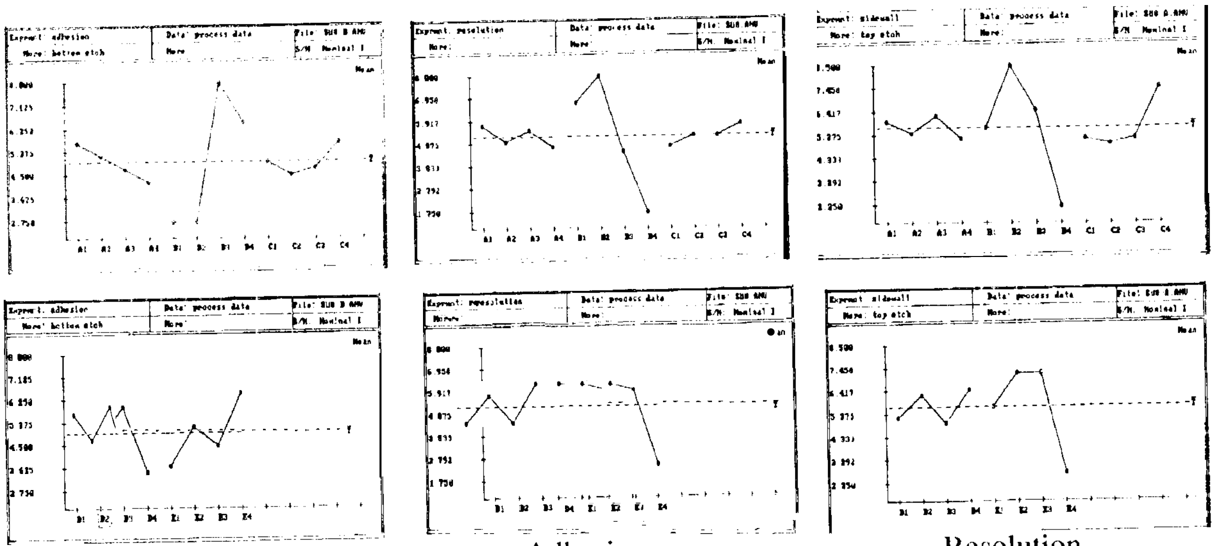


Figure 9 Process parameters vs film thickness



Sidewall

Adhesion

Resolution

Figure 8 output of sensitivity Analysis